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LASER WELDING OF QUARTZ GLASS WORKPIECES

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The problem of fabricating quart-glass cuvettes by welding with CO_2 laser radiation is solved. A thermophysical analysis of the process is performed and its mathematical model is constructed. The welding was performed by two methods — lap and T welding. In both cases the laser radiation parameters were optimized for welding quartz plates.

Key words: quartz glass, laser welding, mathematical model of a thermophysical process, process optimization.

The use of highly efficient laser technologies for processing materials makes it possible to increase workpiece quality to levels not attainable by other methods.

The properties of laser beams such as coherence and monochromaticity of the laser radiation as well as high power levels compared with most other sources make laser beams unique tools for precision heat treatment.

The use of laser radiation for welding glass is desirable in cases where the heated region must be strictly localized and the shape of the workpieces must remain unchanged as much as possible (for example, the quality of the optical surface of the workpieces). The high power density of laser radiation makes it possible to reduce the heated zone to a minimum and to preserve completely the geometry of the workpieces [1 – 4].

WELDING QUARTZ GLASS

Quartz glass has a special place in modern instrument building. It possesses a number of properties that make it irreplaceable in the optoelectronic industry.

The following qualities of quartz glass are especially valuable:

– the highest light transmission among oxide glasses;

– much smaller linear thermal expansion coefficient than in other kinds of glass — CLTE (about $5.5 \times 10^{-7}\ K^{-1}$), making it possible to use in optics quartz glass optical elements which must be minimally sensitive to temperatures variations;

– good dielectric properties.

The conventional method of welding quartz glasses used a gas burner, but this method has a number of important drawbacks:

– low accuracy of the finished article because the heating zone is large;

– additional processing of the article is required;

– consumable materials (gas mixture) must be used.

For high quality quartz articles it is necessary to develop and adopt new technologies for processing quartz glass, which would provide the accuracy and reliability required for the finished articles.

The complexity of the work is due to the following conflict: the localized nature of the action of the laser radiation, which is useful in the case at hand, results in large temperature gradients and makes it necessary to take special measures to prevent glass workpieces from breaking during and after welding. For this reason, special techniques, accessories, and equipment are required to laser weld glass workpieces. Ordinarily, to keep an oxide glass workpiece from cracking during welding it is heated to temperature 500 – 550°C. The need for heating makes the process of welding such glasses much more complicated.

The technology for laser welding of quartz glasses differs in a number of ways from welding of oxide glasses. Because of its low thermal expansion coefficient quartz differs by its high heat resistance and by the fact that it withstands considerable temperature gradients without breaking. In turns out that this fact makes the technology of welding quartz glass simpler than for ordinary oxide glasses because

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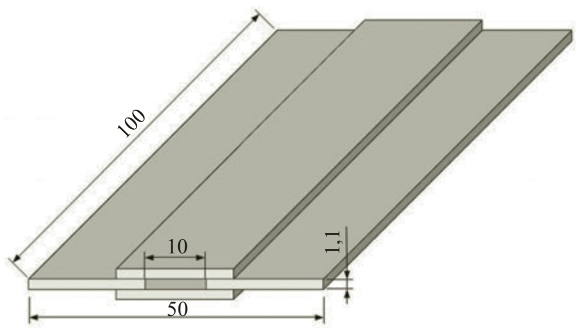

Fig. 1. Cuvette made of quartz glass.

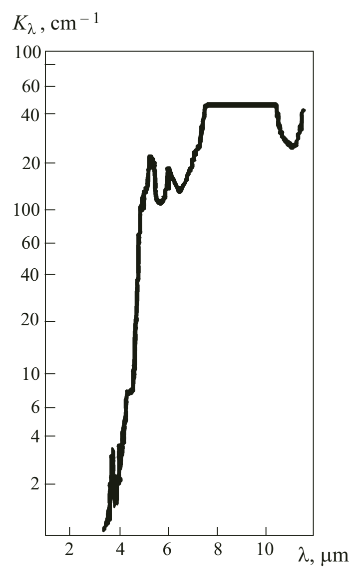

Fig. 2. Spectrum of the absorption coefficient K_λ of quartz glass versus the wavelength λ.

there is no need for preliminary heating and subsequent quenching.

Most studies are concerned with laser welding of quartz with a circumferential seam [1 – 4]. Such seams have high symmetry and are relatively easy to weld from the computational and technological standpoints. A special feature of this work became the problem of welding a quartz-glass cuvette using rectilinear seams according to the scheme shown in Fig. 1. The main requirement for the seam was that the article obtained must be impermeable to gases. The difficulty of this operation is that the weld is asymmetric.

The combination of the optical and thermophysical properties of quartz glass determines the type of laser that can be used effectively to perform the welding. The wavelength of the laser radiation must lie within the absorption spectrum of the glass. Figure 2 shows the IR part of the absorption spectrum of quartz glass. A 10.6 μm CO_2 laser was chosen as most suitable for this job.

To solve this problem a thermophysical analysis was performed of the process of welding quartz glass by laser radiation.

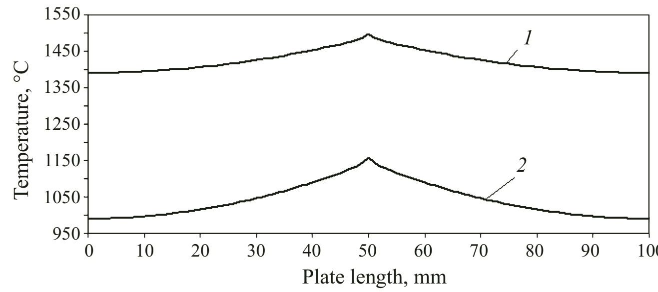

Fig. 3. Temperature distribution in quartz (*1*) and borosilicate (*2*) plates.

THERMOPHYSICAL ANALYSIS OF THE LASER WELDING PROCESS

The mathematical model of the process of laser welding quartz glass is based on the standard heat-conduction equation with an additional equation taking account of the strength of the internal heat source which in this case is the laser beam:

$$\frac{\partial T}{\partial \tau} = a\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \frac{P}{c\rho h}, \quad (x, y, z) \in \Omega, \quad (1)$$

where T is the glass temperature; τ is the time; a is the thermal diffusivity of the glass; c is the specific heat of the glass; ρ is the density of the glass; h is the absorption depth of the laser radiation in the glass; Ω is the computational region; P is the power density in the laser spot, calculated as follows:

$$P(x, y, z) = (1 - R)\, I \exp(-\beta H(x, y))/S, \quad (2)$$

S is the area of the laser spot; I is the laser intensity; R is the reflection coefficient of the glass; β is the absorption coefficient of the glass; the function $H(x, y)$ depends on the type of weld (lap or T); d is the diameter of the laser spot; and, v is the speed of the laser spot.

The initial and boundary conditions are:

$$T(x, y, 0) = T_{av}, \quad (3)$$

$$\lambda \frac{\partial T}{\partial n} + \alpha(T - T_{av}) = 0 \text{ for } (x, y, z) \in \Gamma, \quad (4)$$

$$T(x, 0, z) = T_{sub}, \quad (5)$$

where λ is the thermal conductivity of the glass; α is the coefficient of convective heat transfer; T_{av} is the temperature of the surrounding medium; and, T_{sub} is the temperature of the metal substrate.

Figures 3 and 4 display the results of the numerical calculations for quartz and borosilicate glasses. The calculation was performed for 30 and 50 W lasers. The laser spot diameter was 1 mm, the speed of the laser spot was 20 mm/min,

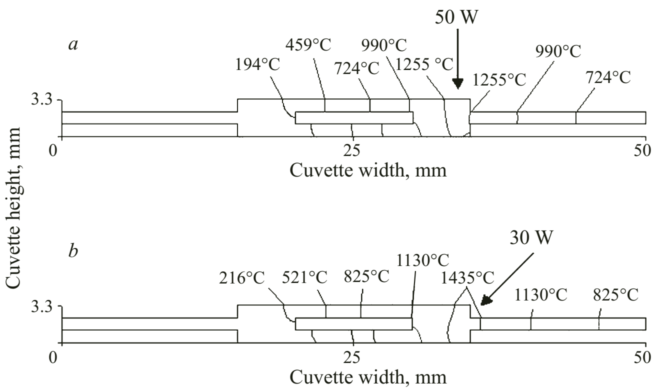

Fig. 4. Temperature fields in a quartz plate for different types of welding with different laser powers: *a*) lap weld; *b*) T weld.

and the total thickness and length of the plate were 2.2 mm and 100 mm, respectively.

EQUIPMENT FOR LASER WELDING OF QUARTZ GLASS

The ULT-03 setup, developed by the Federal State Unitary Enterprise S. A. Lavochkin Scientific–Industrial Association, is intended for laser processing of blanks made of different types of glass, silicon, sapphire, crystalline quartz, and other brittle nonmetallic materials.

WELDING TECHNOLOGY FOR QUARTZ PLATES

To determine the optimal welding regimes the interdependence of the main parameters of the laser welding process was studied experimentally: the laser radiation intensity, speed of the laser spot, and position of the focus of the laser beam relative to the workpiece plane at the penetration depth of the weld channel. Quartz plates 1.1 mm thick were welded using two different schemes — lap weld (Fig. 5*a*) and T weld (Fig. 5*b*).

The optimal welding regimes were found for both methods.

The optimal welding parameters for the T weld were as follows:

– CO_2 laser power 35 W;
– welding speed 20 mm/min;
– diameter of the focused beam 1 mm.

The optimal welding parameters for the lap weld are as follows:

– CO_2 laser power 50 W;
– welding speed 20 mm/min;
– diameter of the focused laser beam 0.7 – 0.8 mm.

The experiments showed that the best seam quality in both cases is obtained with the laser beam focused on the surface of the workpiece.

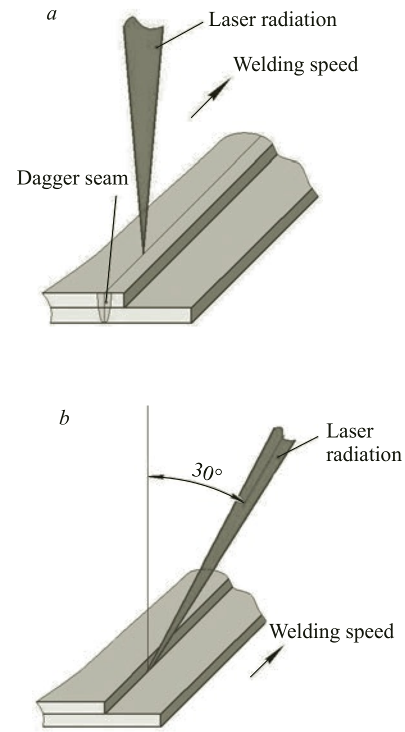

Fig. 5. Welding of quartz plates: *a*) lap weld; *b*) T weld.

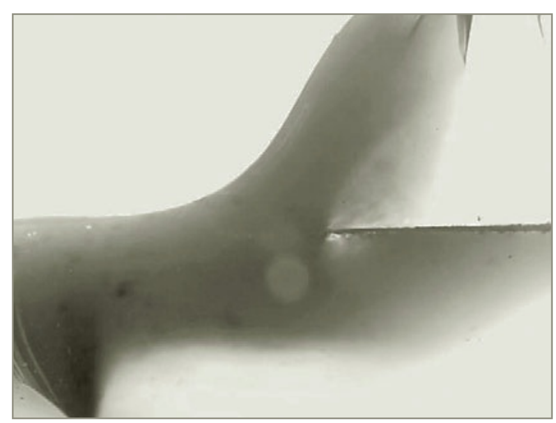

Fig. 6. T weld in laser welding of quartz glass.

The formation of a zone of stable melting of the quartz plates is seen clearly in Fig. 6. The minimal size of the heat-effect zone, which preserves the overall geometry of the cuvette, should be noted.

CONCLUSIONS

Optimization of the CO_2 laser welding regimes made it possible to obtain a uniform weld seam with a minimal heating zone (about 1 mm wide) with high seam strength and reliability. The seams were impermeable to gas. A photograph of the welded cuvette is displayed in Fig. 7.

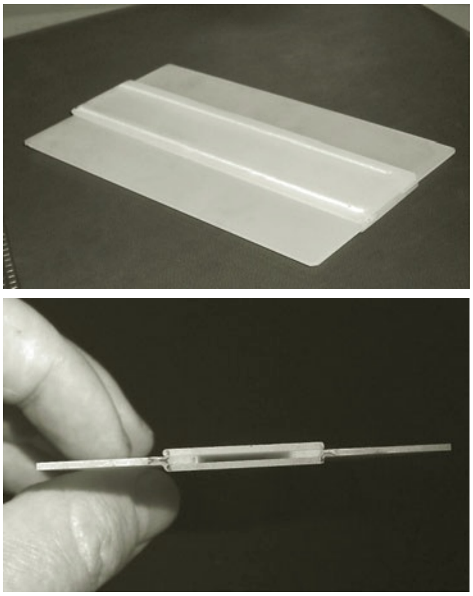

Fig. 7. Welded cuvette.

The economic efficiency of this process should be especially noted: the article was obtained with minimal energy consumption, which can play an important role in using laser welding of quartz glass in serial and mass production.

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REFERENCES

1. G. A. Machulka, *Laser Processing of Glass* [in Russian], Sov. Radio, Moscow (1979).
2. V. S. Kondratenko, V. E. Borisovskii, and P. D. Gindin, *Welding of Quartz Glass* [in Russian], IRVI-VOLEI, Moscow (2006).
3. V. K. Sysoev, *Laser Processing of Oxide Glasses* [in Russian], RKhTU im. D. I. Mendeleeva, Moscow (2011).
4. V. I. Masychev, *Application of a CO Laser for Thermal Processing of Electrovacuum Glasses* [in Russian], MGIÉM, Moscow (2001).